Characteristics of Functionally Modified Foamed Concrete by Nano-Silica

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Abstract: **This paper investigates the influence of nano dispersed additives such as an amorphous nano silicon dioxide (nano-SiO2) on the characteristics of cellular foamed concrete. The most significant issue for all nanoparticles is that of effective dispersion in the complex mix. This study attempts to improve the concrete microstructure by using nano-SiO_2 modified foam in order to produce concrete with highly densed microstructure. The organic foaming agent is functionally modified by dispersingthe predetermined percentage of nano-SiO_2 particles by means of ultrasonication. The nano modified foaming agent is used to generate foam and is then used in the foam concrete production process. The cubes and cylinders were casted and the properties of nano modified foamed concrete samples are characterized based on their functional changes by using micro analytical characterisation techniques such as XRD and FT-IR. The strength studies are correlated based on the results obtained. It is established that nano-SiO_2 used as additive in foam production process acts as nucleators of crystallization influencing the hydration process and structure formation leading to increase in crystallinity of hardened binding material. The strength results indicated a very marginal increase in compressive and flexural strength of concrete.**

Keywords—cellular concrete, FT-IR, foaming agent, foamed concrete, hydration, nano silicon dioxide, XRD

I. Introduction

Concrete can be tailored by the incorporation of nanoparticles and nanotubes to control material behaviour and add novel properties by the grafting of molecules into cement particles, cement phases, aggregates, and additives to provide surface functionality. Several challenges will need to be solved to realize its full potential, including the proper dispersion of the nanoscale additives, scale-up of laboratory results and implementation on larger scale, and a lowering of the cost benefit ratio. Nanosized particles have a high surface area to volume ratio providing the potential for tremendous chemical reactivity when it is admixed. Till date, much of the work has been reported with the use of nano-silica (nano-SiO_2), nano-titanium oxide (nano-TiO_2), or incorporating nano-iron (nano-Fe_2O_3), nano-alumina (nano-Al_2O_3), carbon nanotubes (CNTs) and nano-clay particles. The addition of nano-SiO_2 has been found to improve concrete workability and strength [1,2,3] and has increased resistance to water penetration [4]. Even the addition of small amounts (0.25%) of nano-SiO_2 is observed to increase the strength, improving the 28 day compressive strength by 10% and flexural strength by 25% [1]. Addition of 10% nano-SiO_2 with dispersing agents is observed to increase the compressive strength of cement mortars at 28 days by as much as 26%, compared to only a 10% increase with the addition of 15% silica fume [3]. Nano-SiO_2 also accelerates the hydration reactions of both C_3S and an ash–cement mortar as a result of the large and highly reactive surface of the nanoparticles [5,6]. Nano-SiO_2 is found to be more efficient in enhancing strength than silica fume [7,8]. It is noted that the results obtained depends on the production route and conditions of synthesis of the nano-SiO_2 (e.g., molar ratios of the reagents, type of reaction media, and duration of the reaction for the sol–gel method) and that dispersion of the nano-SiO_2 in the paste plays an important role. Nano-SiO_2 not only behaved as a filler to improve the microstructure but also as an activator to promote pozzolanic reactions [7].

One of the methods recently employed to improve the technical characteristics of concrete is the use of additives consisting of nano dispersive particles. Only very few papers have reported the use of nano additives in the production of foamed concrete. Foamed concrete is classified as light weight concrete, in which air voids are trapped in mortar by suitable foaming agent. Grigorij et al. [9] investigated the use of carbon nanotubes (0.05% by mass, dia 100nm and length 20μm), which is synthesized from aromatic hydrocarbons and used as reinforcement for the production of foam non-autoclave concrete, allows to decrease its heat conductivity up to (12 – 20) % and to increase its compressive strength up to 70 %. The microstructure investigation results have shown a better pore size uniformity in foam concretes containing an admixture of carbon nanotubes. In concretes without carbon nanotubes, due to intensive percolation of wall pores causes them to combine into larger ones, which in turn increases the heat conductivity of the foam concrete and deteriorates its maintenance characteristics. Alireza Fiouz and Sina Saadat

[10] investigated the properties of foamed concrete containing nano-silica (12nm and 1 to 6% of the cement weight), and micro-silica (230nm and 1 to 6% of the cement weight), as well as comparing the properties of these two concretes with the witness concrete. The increase of 1 to 6% of nanosilica particles in foamed concrete contributes to an increase in the amount of concrete compressive strength, as compared with the witness sample.The micro structural examination of the foamed concrete by using the SEM images suggests the improvement in the concrete micro structure and mechanical properties containing nano-silica.

In the present study, instead of partial replacement of cement weight by nano additives, the foaming agent is functionally modified by dispersing the predetermined percentage of nano-SiO_2 by means of ultrasonification. The stability of foam is disturbed by various factors such as pressure, temperature, pH etc. The nano modified foaming agent is used to generate foam in the foam concrete production process and is found to be visually stiff and stable.

II. EXPERIMENTAL PROGRAMME

Light weight foamed concrete (LFC) is a type of porous concrete, produced by mechanical mixing of foam (bubbles of size 0.1–1.0mm) prepared in advance with the concrete mixture composed of cement-sand-flyash matrix. Foam is prepared in a special device called foam generator and later mixed by using special mixer. By controlling the dosage of foam, density range of 200–1600 kg/m^3 can be attained for application as structural, partition and insulation material. In this investigation, three concrete mixture designs have been utilized. The density of mix remains same as 1200 kg/m^3 for all the three mixes. Only the percentage of nano-SiO_2 added to the organic protein foaming agent is varied as 0.5% and 2% of the foaming agent weight.

A. Materials

The production of LFC with a density of 1200kg/m^3 is carried out by using raw materials that consisted of ordinary Portland Cement (OPC) of 53 grade conforming to IS:12269[11], fine river sand passing through 1.18mm sieve conforming to IS:383[12], Class F flyash conforming to ASTM C618[13], potable water, protein based foaming agent and nano-SiO_2 as additive. The SiO_2 nano powder (Purity 99%, 20-30nm, amorphous) used in this study is commercially bought from M/s NANOSHEL, USA.

B. Mix proportions

The specification concerning the witness sample mixed design for the dry density of 1200 kg/m^3 is shown in Table 1. Protein based chemical is used for the preparation of foam. One kg of chemical can produce 660 litres of foam. The water-binder ratio is kept constant as 0.31 and the cement-sand ratio is maintained as 1:0.87 for all the mixes. The stable foam with a density of 75 kg/m^3 is produced by using the dry preformed foam method. The foaming agent is diluted with water at a volumetric ratio of 1:30. The nano-SiO_2 is added to this mixture and then compressed by a compressor under 4.75 kgf pressure to generate the foam.

C. Ultrasonification

The dispersing and deagglomeration of solids into liquids can be carried out by ultrasonic devices. Ultrasonic cavitation generates high shear forces that break particle agglomeration and disperse into single particles. The mixing of powders into liquids is a common step in the formulation of various products, such as paint, ink, shampoo, beverages, or polishing media. The individual particles are held together by attraction forces of various physical and chemical nature, including van der Waals forces and liquid surface tension.

TABLE I CONTROLLED SPECIMEN MIX DETAILS

Constituent Material (Dry Density 1200 Kg/M^3)	**Material Content (For1m^3) (Kg)**
Cement	356
Fly Ash	285
Sand	310
Water	200

The attraction forces must be overcome in order to deagglomerate and disperse the particles into liquid media. For the dispersing and deagglomeration of powders in liquids, high intensity ultrasonication is an interesting alternative to high pressure homogenizers and rotor-stator-mixers. In this study, the nano-SiO_2material is added to the diluted mixture of foaming agent and subjected to ultrasonication for one hour with 45% amplitude.

D. Specimens Preparation

In the mixing procedure, cement, sand and flyash are added to water and mixed thoroughly in the special mixer. To this mixture, the required quantity of preformed foam is then added to achieve the density of 1200 kg/m^3. In this investigation, three concrete mixture designs have been utilized. The specimens were given the names. Mix 1, Mix 2 and Mix 3. The mix details and the volume of foam required to achieve the desired density are tabulated in Table 2. The Mix 1 specimen is the witness sample (foam concrete sample without nano additive). The Mix 2 and Mix 3 specimens contains nano-SiO_2 as additive equal to the weight of 0.5% and 2% of the foaming agent respectively. The cube mould with dimension of 50×50×50 mm and cylinder moulds with dimension of 50mm dia and 100mm length were used. The specimens were de-moulded 24 hours after casting and were subjected to water curing condition in the room temperature. The volume of foam required for all the mixes is almost same for all the mixes as observed from Table II.

TABLE II SPECIMEN DETAILS

Specimen name	Description	Volume of foam required for density 1200 kg/m^3 (gm)
Mix 1	Witness sample	686
Mix 2	Nano-SiO_2 (0.5% of weight of foaming agent)	699
Mix 3	Nano-SiO_2 (2.0 % of weight of foaming agent)	710

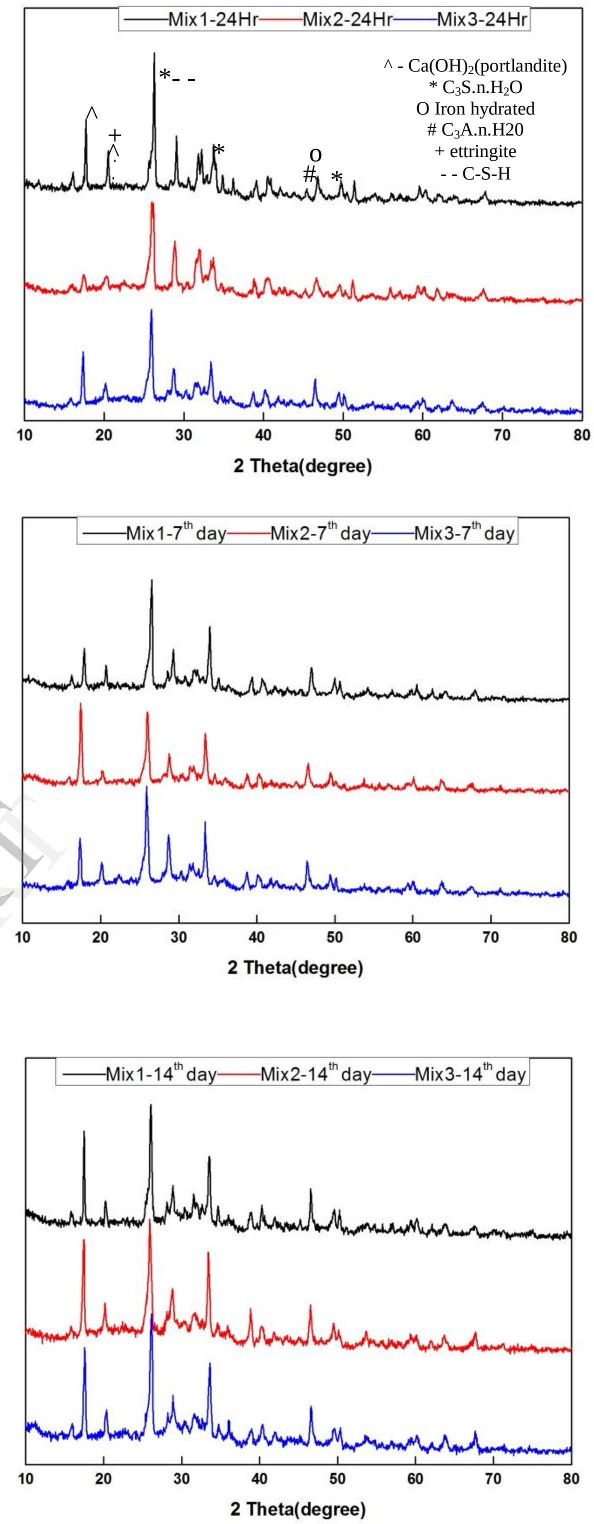
III. HYDRATION AND CHARACTERISATION STUDIES

Understanding and interpreting the chemical and micro structural phenomena of different steps of the intrinsic cement hydration process through micro- analytical characterization are quite complex and interdependent. Resolving the individual mechanisms or the parameters which determine the key factor of hydration rate is pretty difficult. Therefore, fundamental studies of hydration offer significant scientific challenges in the experimental techniques which leads to develop multi-scale theoretical modelling methods to get to the bottom of the problem. Hence hydration study is very much required to link the strength parameters with fundamental liquid/solid state reaction of cement phases. Furthermore, proper functionalisation methods are adopted to achieve absolute efficiency in foamed cementitious composites. The mixes as prepared for the strength studies are used for conducting hydration studies. For this study the samples are collected at the time intervals of 24 hrs, 7, 14 and 28 days. Hydration is stopped by pouring acetone on to the samples at each intervals and they are dried and kept in vaccum dessicator in order to avoid carbonation and moisture attack until the testing day.

A. XRD studies

These studies are conducted to study the hydration phases at each intervals for all the mixes and the same are shown in Fig 1 and the corresponding peaks for the hydrated products are highlighted. From the XRD pattern, it is evident that hydration process is not postponed by the addition of nano-SiO_2 as the required phase for strength development such as hydrates of calcium silicates, aluminates, ferrites, ettringites are well formed. It is important to note that cement hydration involves a collection of coupled chemical processes and all of them occurs at a rate which is determined both by the nature of the process and by the state of the system at that instant. Based on their processes it will fall into one of the following categories:

1. Dissolution/dissociation, 2. Diffusion, 3. Growth, 4. Nucleation, 5. Complexation, 6. Adsorption



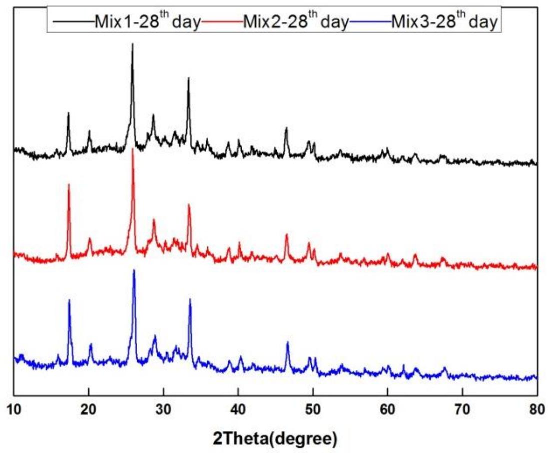
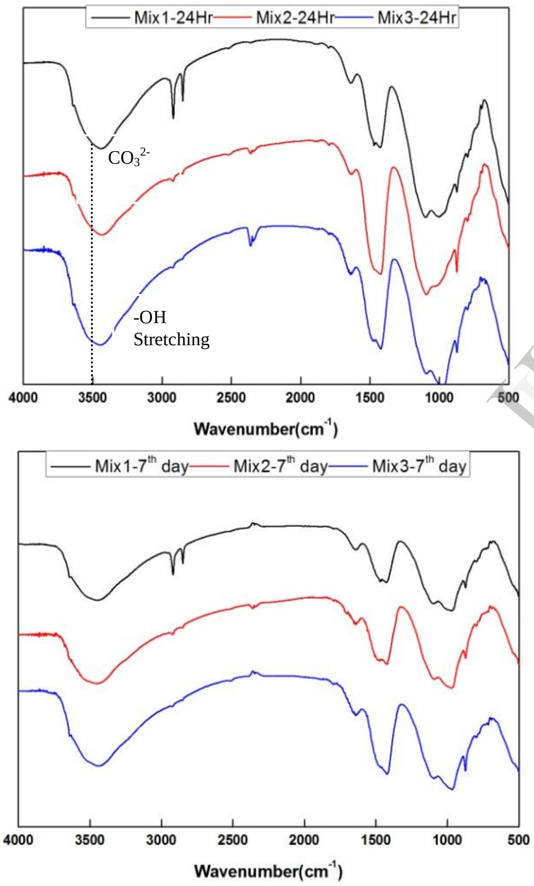


Fig 1. XRD pattern of the functionalised and non-functionalised hydrated foam composites at different intervals



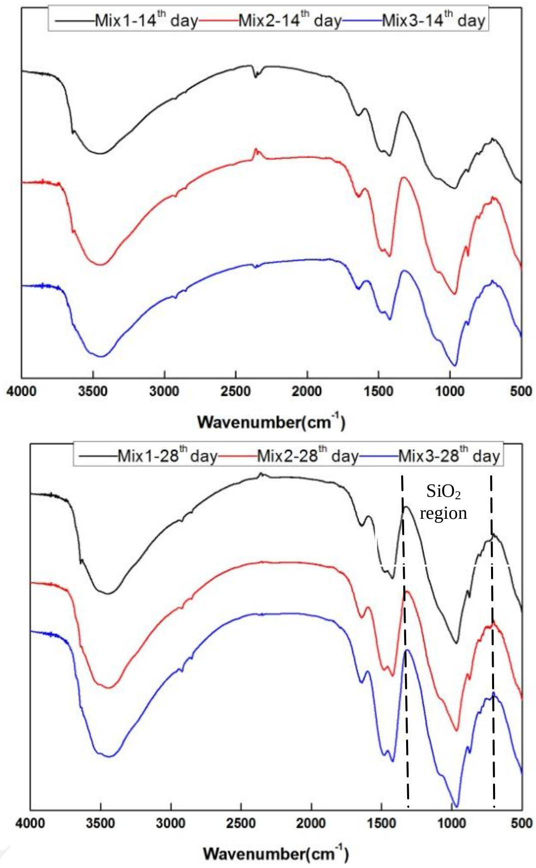


Fig 2. FT-IR pattern of the functionalised and non-functionalised hydrated foam composites at different intervals

Sometimes these processes may operate in series, in parallel, or in some more complex combination. In the present case addition of nano moiety has preponed the formation of semi crystalline C-S-H, as the hydrophobic tail of SiO_2 is attached with organic binder (foaming agent). Hence the dissolution rate is kinetically controlled by the addition of nano moiety, but this is not happened in the witness sample. Further, the solid growth also enhanced and the same which is evidenced by the peak broadening effect in the presence of nano moiety. In addition, alite (C_3S) tends to dominate the early hydration period in the case of nano modified foam mixes, which comprises setting and early strength development as the component is most responsible for formation of the calcium silicate hydrate gel (C–S–H), the principle product of hydration.

B. FT-IR – Functional Group Studies

In order to characterize the functional groups presence, FT-IR studies have been carried out on the corresponding mixes and the same have been shown in Fig 2. According to the pattern which have been obtained from this study prove that, an efficient bonding have occured between the cement hydrates and nano SiO_2. The bonding frequency for the nano modified foamed concrete at 3000 cm^{-1}, 2800 cm^{-1} and 1800 cm^{-1} at each intervals prove that the stretching of -OH and CO_3^{2-}, which may be due to the crystal growth of silicate moiety. At the lower frequency region,shift in frequency from 920 cm^{-1} to 980 cm^{-1} at 28^{th} day is observed for the witness and modified samples respectively. This clearly explains the interaction of nano-SiO_2 with cement hydrates and hence early strength development.

C. *Strength Studies*

The strength study refers to the mechanical strength of the concrete with and without the presence of nano additive. The compressive strength and split tensile strength at the age of 7, 14 and 28 days are determined. The results are presented in Table 3. The modification of foam with 0.5% and 2% of nano silica particles in foamed concrete contributes to only a slight increase in the amount of concrete compressive strength and the split tensile strength as compared with the witness sample. Further, characterisation studies also helps in understanding the reason behind enhanced mechanical strength for the functionalised foamed concrete.

TABLE III STRENGTH RESULTS

Specimen ID	Compressive strength N/mm^2			Split tensile strength N/mm^2		
	7th day	*14th day*	*28th day*	*7th day*	*14th day*	*28th day*
Mix 1	4.72	5.50	8.56	3.80	4.32	5.40
Mix 2	5.01	6.10	8.62	4.00	4.21	5.70
Mix 3	5.35	6.52	8.72	4.05	4.51	5.99

IV. SUMMARY AND CONCLUSIONS

This paper investigated the properties of foamed concrete containing nano-silica as additives (added to the foaming agent) with the plain foamed concrete. The strength studies carried out on 7th, 14th and 28th day indicated that the samples produced by using nano-SiO_2 modified foamed concrete has only very marginal increase in the compressive and tensile strength as compared to the witness sample. The hydration studies by using XRD have shown the formation of strength development products such as hydrates of calcium silicates, aluminates, ferrites and ettringites. The pattern obtained from FT-IR studies have shown the interaction of nano-SiO_2 with cement hydrates and hence early strength development as compared to the witness sample.

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